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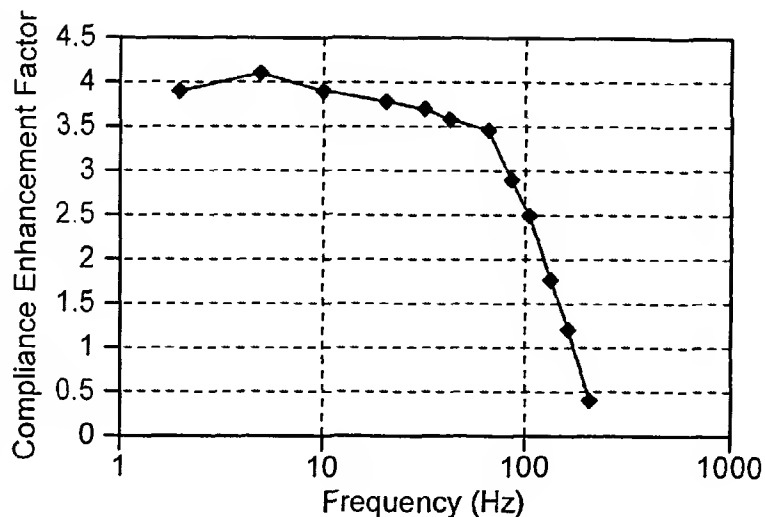
(57) Abstract: An acoustic enclosures such as a loudspeaker (10) uses within the cabinet adsorbent material, and/or containment means (22) for the adsorbent material, which is at least partially hydrophobic. Preferably, the material is activated carbon treated to provide it with hydrophobic properties. Preferably, the adsorbent material is treated with a silicon-containing compound. This improves the acoustic compliance of the acoustic enclosure.

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IMPROVEMENTS IN ACOUSTIC ENCLOSURES

Field of the invention

5   This invention relates to acoustic enclosures such as
loudspeakers, and in particular to the achievement of
maximum bass performance from a minimum size of loudspeaker
cabinet.

10 ### Background to the invention

       Numerous attempts have been made to extend the low
frequency performance of small loudspeaker systems.
However, none of these have so far proved to be successful
15 commercially.
       In GB2146871B there is described a technique for
eliminating or substantially eliminating pressure
variations in an essentially closed volume, such as the
interior of a loudspeaker cabinet. The essentially closed
20 volume of the cabinet is effectively reduced in volume when
the loudspeaker cones make excursions into the interior of
the cabinet. Such excursions tend to increase the pressure
in the cabinet and these pressure variations are reduced '
by locating a mass of material within the cabinet, the
25 material being adsorbent to the gas or vapour in the
cabinet. The adsorbing material can be a mass of activated
charcoal or carbon in granular form. The granules are
described as being held in place by a mesh-like support
structure which can be a moulding of plastics material or
30 formed from expanded metal sheet. This can be lined with a
porous fabric such as filter paper to prevent small
granules from passing through the support structure.
       In GB2146871B it is mentioned that it is desirable to
keep the carbon granules free from moisture. Methods of

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attempting to achieve this described in the aforesaid
patent specification include the provision of a moisture
impermeable diaphragm located within the box between the
granules and the speakers, and also the use of a moisture
5 barrier to prevent moisture from entering the region of the
mass of carbon granules.

US 5,857,340 discloses the use of carbon for
preferential adsorption of one of a mixture of gases in the
acoustic resonator of a thermoacoustic resonator.

10   US 5,080,743 discloses a method of forming an acoustic
diaphragm formed wholly from carbonaceous materials,
including crystals of graphite.

Although the use of adsorbent materials in acoustic
enclosures may be beneficial, there exist problems with the
15 practical use of such materials.

When a loudspeaker cone moves backwards, the air in
the box is compressed slightly. In a conventional
loudspeaker this results in a pressure increase which acts
to impede the movement of the cone. In a cabinet in
20 accordance with the invention, the pressure increase is
smaller because some of the air molecules are momentarily
joined to the surface of the carbon granules (adsorbed).
So the impedance to motion is significantly reduced. When
the cone moves forwards the air molecules are desorbed by
25 the resulting pressure decrease.

One can think of this adsorption as a (temporary)
reduction of air density. The acoustic compliance of air
in the loudspeaker cabinet is given by:

$$C_A = V_B / \rho c^2$$

30 where V_B is the nett enclosure volume

ρ is the density of air

c is the velocity of sound in air

Therefore a reduction in density produces an increase
in compliance, equivalent to enlarging the enclosure.

35   This stiffness reduction or compliance enhancement can

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be as much as four times or more under optimum conditions.
Factors of 1.5 to 3 are readily achievable in practice.

The compliance enhancement achieved with the present
invention is principally effective at low frequencies, as
5 shown in Fig. 1. At higher frequencies than about 200Hz
performance deteriorates because the cycle time becomes too
short for adsorption and desorption fully to take place.

There is a strong relationship between the tendency of
an activated carbon to adsorb air and its tendency to
10 adsorb water vapour. Adsorption of water vapour adversely
affects compliance enhancement because the water molecules
block the pores and prevent air adsorption. Therefore the
carbon must be kept as dry as possible, and its "water
uptake" should be minimal.
15

Summary of the invention

The approach, which is the subject of the present
invention, is to use adsorbing material and/or the
20 containment means for it which is at least partially
hydrophobic, i.e. water-repellent. In this way one can
achieve acoustic compliance enhancement of the loudspeaker,
i.e. an improvement in the acoustic compliance. In other
words, the loudspeaker cabinet can be made to seem
25 acoustically bigger without any physical change to the
cabinet. Alternatively, the same acoustic output can be
obtained with a cabinet of smaller size.

In addition to being used within loudspeaker cabinets,
such adsorbent materials may also be used in other types of
30 acoustic enclosures. In particular, sound recording
studios have walls which incorporate air gaps, wadding and
the like in order to improve sound proofing. Instead of,
or in addition to, such traditional features, such rooms
may incorporate the hydrophobic adsorbent material of the
35 invention, conveniently located within the walls of the

. 4

room. The thickness of sound-proofing structures in the
walls may then be reduced, thus increasing the usable space
of the room.

    In accordance with one aspect of the present invention
5 there is provided an acoustic enclosure within which there
is an adsorbent material which is or which has been treated
to make it at least partially hydrophobic.

    In accordance with another aspect of the present
invention there is provided an acoustic enclosure within
10 which there is located adsorbent material which is within
containment means which is or which has been treated to be
at least partially hydrophobic.·

    Clearly, it would also be possible within the scope of
the invention both to use hydrophobic adsorbent material
15 and also to make the containment means water-repellent as
well.

    The adsorbent material is preferably activated carbon,
suitably treated to provide it with hydrophobic properties.

    Preferably, the adsorbent material comprises a
20 silicon-containing compound.

    Other materials which could be used include alumina,
silica, zeolite and aerogel, which are highly adsorbent.

    A factor which needs to be considered in the design of
a loudspeaker cabinet containing such compliance
25 enhancement material is how the material is to be presented
to the air. Desirably, one needs to achieve maximum
exposure of surface area to the air within the cabinet.
Whether one uses hydrophobic carbon and/or a water-
repellent containment material, it is desirable not to use
30 a large solid mass of compliance enhancement material, but
to use a modular arrangement, for example of tubular bags
of material linked together by webbing. Such tubular bags
can be laid in layers, at right angles to one another, to
give little contact between the individual bags and an
35 optimum surface area of exposure to the air.

5

Alternatively, a number of tubular bags of material can be arrayed in the form of a curtain within the cabinet, again with a view to achieving maximum exposure of the material to the air.

5   If the compliance enhancement material, such as hydrophobic carbon, is contained within a bag or bags, the bag material can be a multi-filament synthetic textile material.

References herein to the compliance enhancement 10 material being hydrophobic is not intended to exclude materials which are not 100% hydrophobic. The invention is intended to cover compliance enhancement materials which have been treated to improve their hydrophobic qualities, even if they cannot be said to be truly hydrophobic. The 15 same is true in respect of the containment material. Material treated to improve its water-repellent characteristics is to be regarded as falling within the scope of the present invention, even if the material is not then 100% water-repellent.

20

Brief description of the drawings

The invention will now be described in more detail, by way of example, and with reference to the accompanying 25 drawing, in which:

Fig. 1 is a graph showing the compliance enhancement factor plotted against frequency for a typical loudspeaker in accordance with the invention;

Fig. 2 is a view, partly cut away, of a loudspeaker 30 cabinet in which adsorbent material is encased in vertically arranged tubular modules; and,
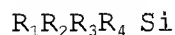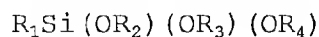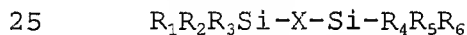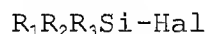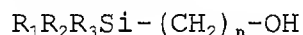
Fig. 3 is a graph of water adsorption isotherms of treated and untreated activated carbons.

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Description of the preferred embodiments

Fig. 2 shows a loudspeaker cabinet 10 with a front
wall 12, rear wall 14 and side walls 16. Two drive units
5 18, 20 are shown. Each side wall 16 is curved to
accommodate a plurality of vertical tubular bags 22
containing compliance enhancement material in accordance
with the invention. The bags 22 may be linked together on
each side of the cabinet by webbing. The bag material can
10 be a multi-filament synthetic textile material. The bags
thus function as curtains within the enclosure and present
a large surface area.

It has been found that the treatment of activated
carbons with certain agents increases their hydrophobicity,
15 i.e. that they adsorb less water than untreated carbons, at
a certain relative humidity. In particular, the treatment
of carbons with silicon-containing compounds can increase
their hydrophobicity. Suitable silylating agents include
both activated compounds (eg silyl halides and esters) and
20 non-activated compounds (eg silyl alcohols) with a range of
substituents, and include those having the following
general formulae:

$$R_1R_2R_3Si-(CH_2)_n-OH$$
$$R_1R_2R_3Si-Hal$$
25 $$R_1R_2R_3Si-X-Si-R_4R_5R_6$$
$$R_1Si(OR_2)(OR_3)(OR_4)$$
$$R_1R_2R_3R_4\ Si$$

where n = 0-20

$x = O$, S or NR_1
30 Hal = halogen
and each of R_1, R_2, R_3, R_4, R_5 and R_6 is independently selected
from the group consisting of,

hydrogen, optionally substituted, branched and
unbranched alkyl, alkenyl, alkynyl or aryl groups.
35 Specific examples of such R groups include H, Me, Et,

7

Pr, n-Bu, iso-Bu, tert-Bu, allyl, phenyl etc, and specific
examples of suitable silylating agents include:

     trimethylsilyl ethanol (TMSE)
5   hexamethyldisiloxane (HMDSO)
     methyltrimethoxysilane (MTMS)
     propyltrimethoxysilane (PTMS)
     iso-butyltriethoxysilane (i-BTES)
     octyltriethoxysilane (OTES)
10

     The silylating agent or agents may be incorporated in
the carbon in a number of ways. The carbon may·be dipped
into a solution of the silylating agent and then dried, or
it can be sprayed with the silylating agent, or the
15 silylating agent may be vapourised and adsorbed onto the
carbon, or the carbon may be chemically, activated prior to
or during these steps, for example by treatment with a
catalyst or base and treatment with an activated compound
such as tert-butyldimethylchlorosilane. These steps may be
20 performed at, below or above ambient pressure and
temperature.
     Examples of the incorporation of silylating agents
into activated carbons will now be described, along with
properties of the resultant treated carbons.
25

Experimental

     All of the starting materials and reagents used herein
are commercially available or have published syntheses.
30 For example, a range of untreated activated carbons are
available from Sutcliffe Speakman Carbons Ltd of Lockett
Road, Ashton-in-Makerfield, Lancashire, WN4 8DE, UK. The
silicon-containing compounds are available from such
sources as the Sigma-Aldrich Company Ltd of The Old
35 Brickyard, New Road, Gillingham, Dorset, SP8 4BR, UK.

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Organosilane Impregnation Method

A quantity of granular activated carbon, which had
been pre-conditioned at 120°C for a minimum of 4 hours in a
5 fan assisted drying oven then cooled to ambient conditions
in a desiccator over silica gel, was accurately weighed
into a glass dish fitted with a ground glass lid. The
glass dish and weighed activated carbon were placed into a
temperature controlled heated oven together with the
10 separate ground glass sealing lid. The oven temperature
set-point was dependent upon the respective boiling point
of the organosilane (or organosilyl) impregnant. An oven
temperature of 20°C higher than the corresponding
organosilane boiling point was required.
15   The amount of organosilane compound to be added was
calculated such that it would produce the degree of
impregnation required with respect to the weighed activated
carbon. The required amount of organosilane-based liquid
was weighed into a small glass phial which was then
20 carefully placed, separately, with the heated activated
carbon within the glass dish. The heated dish and contents
were then sealed by the lid and replaced into the heated
oven. Frequent visual inspection determined when full
vaporisation/adsorption of the organosilane compound onto
25 the heated adsorbent carbon had been achieved. The sealed
glass dish and contents were removed from the hot oven and
cooled. The increase in carbon weight was determined.
Percentage weight/weight organosilane-based addition
was calculated by:-
30   *% w/w additive = A x 100/(C + A)*
where *C = original weight of carbon*
where *A = weight increase of carbon*

Example 1. Trimethylsilylethanol (TMSE) 3% w/w addition
35   Activated carbon: Highly activated coconut shell

Dried carbon weight: 1.9400g

Boiling point TMSE: 73°C

Oven temperature: 93°C

Weight increase: 0.06g

5   % w/w TMSE: 0.06 x 100/(1.94 + 0.06) = 3.0%

Example 2. Hexamethyldisiloxane (HMDSO) 6% w/w addition

Activated carbon: Highly activated coconut shell ·

Dried carbon weight: 1.8800g

10 Boiling point HMDSo: 101°C

Oven temperature: 121°C

Weight increase: 0.12g

% w/w HMDSO: 0.12 x 100/(1.88 + 0.12) = 6.0% w/w addition

15

Determination of water uptake as a function of relative pressure at 25°C

In determining the property of water adsorption, a dynamic
20 method involving the adsorption of water vapour from a generated
air stream was considered as the most suitable which would
represent adsorption conditions envisaged in practice. An
experimental rig, as briefly described below, was constructed to
generate air/water mixtures. "Pyrex" glassware and standard ground
25 glass joints were employed throughout.

A flow of air was dried and purified by passage through a
series of towers containing activated carbon, silica gel, and
silica gel + soda lime respectively. The conditioned air stream
was divided to pass through two calibrated flow rotameters. The
30 two air streams from the flowmeters were directed though separate
glass spirals, which were immersed in a thermostatically controlled
water bath at 25°C. One air stream was saturated with water by
passage through a series of two bubbler saturators. The water
saturated air stream was then mixed with a controlled flow of air
35 from the second flowmeter in a mixing bottle immersed in the water

10

bath at 25°C. The mixed air stream was passed through a sorption tube at 25°C that contained a weighed quantity of pre-dried activated carbon.

By controlling and measuring the air flows through the
5 flowmeters it was possible to calculate the partial pressure of water vapour in the resulting mixed air stream.

If a_1 is the flowrate through the water saturators and a_2 that of the pure air stream admixed, and a_3 the increase in rate due to the water vapour then the vapour pressure of water, P, is given by:
10 $P = (a_3 \times P_A)/a_1 + a_2 + a_3)$ and $Ps = (a_3 \times P_A)/(a_1 + a_2)$., where P_A is atmospheric pressure and Ps the saturation vapour pressure of water at the temperature of the test. Combining the two equations, the relative pressure of the water vapour is given by:-

$$P/Ps = a_1/(a_1 + a_2) - (a_2Ps/P_A)$$

15　　　　In practice about 0.5g of pre-dried carbon sample was accurately weighed into a previously weighed sorption tube, which was attached to the mixed flow of humidified air at a set partial pressure. The carbon was allowed time to attain equilibrium with the water vapour air stream. At intermittent times the sorption
20 tube was removed, stoppered and weighed. This procedure was repeated until constant weight had been achieved. Flow rates were then altered to produce a higher partial pressure of water vapour and so on until sufficient points had been obtained to construct the adsorption isotherm. The carbon was then subjected to an
25 airstream flow saturated with water until equilibrium had been achieved.

In constructing the adsorption curve the water uptake as g uptake/100g carbon was plotted against the relative pressure of water vapour P/Ps (*i.e.* % Relative Humidity).
30

Results and Discussion

This observation can be attributed to the reduction of moisture uptake by the activated carbon as recorded in Table 1 in
35 which LM 056 and LM 058 represent laboratory samples of activated

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carbon impregnated with 2.1 and 3.0% of the trimethylsilylethanol
(TMSE), respectively.

Table 1: Trimethylsilylethanol additions - Effect upon Water Uptake

5

Reference No.		1 (control)	2	3
Trimethylsilylethanol/%w/w		None	2.1%	3.0%
P/Po	R.H	Water Uptakes /%		
0	0	0	0	0
0.407	40.7	5.2	3.2	1.9
0.499	49.9	10.1	7.1	3.0
0.606	60.7	21.7	16.3	6.5
0.696	69.6	34.9	23.0	10.0
0.805	80.5	64.0	35.4	19.5
0.901	90.1	64.9	53.2	39.8
1.0	100	67.0	55.7	41.4

(The activated carbon used was highly activated coconut shell)

20   Table 1 shows that water uptake has been reduced to around a
third of the original value between 60 and 80% R.H. Measurement of
the CTC value after impregnation with 3.0% of the TMSE showed a
value of 95% relative to an original CTC value of 111%. This is a
small reduction compared to the reduction in water uptake.

25   Figure 3 is an illustration of the tabulated data and clearly
demonstrates that impregnation of the TMSE significantly reduces
water uptake throughout the range of relative humidities 0 - 100%.
        Further exemplification is presented in Table 2. This shows
the diminution in water uptake for the activated carbon impregnated
30 with a range of organosilyl compounds at 60 and 80% relative
humidities:

TMSE   Trimethylsilyl ethanol $((CH_3)_3-Si-CH_2CH_2OH)$

12

HMDSO	Hexamethyldisiloxane	$(CH_3)_3-Si-O-Si-(CH_3)_3$
MTMS	Methyltrimethoxysilane	$CH_3-Si-(OCH_3)_3$
PTMS	Propyltrimethoxysilane	$CH_3CH_2CH_2-Si-(OCH_3)_3$
i-BTES	iso-butyltriethoxysilane	$(CH_3)_2CHCH_2-Si-(OC_2H_5)_3$
5 OTES	Octyltriethoxysilane	$CH_3(CH_2)_7-Si-(OC_2H_5)_3$

Table 2: Water Uptake at 60 & 80% RH

Ref no.	Compound	Compound Addition (% w/w)	60% RH	80% RH
			Uptake g/100g	
10 4 (control)	None	0	21.7	64.0
5	TMSE	2.1	16.3	35.4
6	TMSE	3.0	6.5	19.5
7	HMDSO	1.6	14.1	33.5
8	HMDSO	3.1	9.8	32.7
15 9	HMDSO	5.6	10.0	25.2
10	MTMS	5.2	7.2	27.5
11	PTMS	5.2	7.3	29.9
12	i-BTES	5.8	5.1	25.0
13	OTES	6.1	6.3	29.1

20

It is to be appreciated that these water-adsorption data are in respect of the equilibrated adsorption of water onto the carbon. It was noted that the dynamic rate of adsorption of water onto the 25 treated carbons was reduced with respect to that of the untreated carbons.
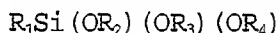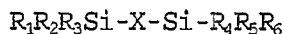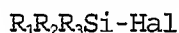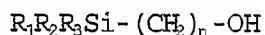
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<u>CLAIMS</u>:

1.   An acoustic enclosure within which there is an adsorbent
material which is or which has been treated to make it at least
5 partially hydrophobic.

2.   An acoustic enclosure within which there is located
adsorbent material which is within containment means which is or
which has been treated to make it at least partially hydrophobic.

3.   An acoustic enclosure according to claim 1 or 2, wherein
10 the adsorbent material comprises activated carbon.

4.   An acoustic enclosure according to any one of the
preceding claims, wherein the adsorbent material comprises a
silicon-containing compound.

5.   An acoustic enclosure according to claim 4, wherein the
15 silicon-containing compound has the formula;

$$R_1R_2R_3Si-(CH_2)_n-OH$$
$$R_1R_2R_3Si-Hal$$
$$R_1R_2R_3Si-X-Si-R_4R_5R_6$$
$$R_1Si(OR_2)(OR_3)(OR_4)$$

20        $$R_1R_2R_3\ R_4Si$$

where n $=0-20$

x $=$ O, S or NR

Hal $=$ halogen

and each of R_1, R_2, R_3, R_4, R_5 and R_6 is independently selected from the
25 group consisting of,

hydrogen, optionally substituted, branched and unbranched
alkyl, alkenyl, alkynyl or aryl groups.

6.   An acoustic enclosure according to claim 4 or 5, wherein
the silicon-containing compound is selected from;

30   trimethylsilyl ethanol (TMSE)

hexamethyldisiloxane (HMDSO)

methyltrimethoxysilane (MTMS)

propyltrimethoxysilane (PTMS)

iso-butyltriethoxysilane (i-BTES)

35   octyltriethoxysilane (OTES)

7.   An acoustic enclosure according to any one of claims 4,
5 or 6, wherein the carbon comprises the silicon-containing

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compound in an amount of from about 0.1wt% up to about 20wt%.

8.   An acoustic enclosure according to any one of claims 4
to 7 wherein the carbon comprises the silicon-containing compound
in an amount of from about 3wt% up to about 6wt%.

5   9.   An acoustic enclosure according to any one of the
preceding claims, wherein the adsorbent material is located within
containment means which comprises a plurality of separate modules
each containing the adsorbent material.

10.   An acoustic enclosure according to claim 9, wherein the
10 containment means comprises a plurality of bags of material which
are linked together.

11.   An acoustic enclosure according to claim 9, wherein the
containment means comprises a plurality of tubes of material linked
by webbing.

15   12.   An acoustic enclosure according to claim 9, 10 or 11,
wherein the containment means comprises a multi-filament synthetic
textile material.

13.   An acoustic enclosure according to any one of claims 1
to 12 wherein the acoustic enclosure is a sound-proofing structure.

20   14.   An acoustic enclosure according to any one of claims 1
to 13, wherein the acoustic enclosure is a room.

15.   An acoustic enclosure according to any one of claims 1
to 12, wherein the acoustic enclosure is a loudspeaker cabinet.

16.   An acoustic enclosure substantially as hereinbefore
25 described with reference to and as shown in the accompanying
drawings.

17.   A loudspeaker substantially as hereinbefore described
with reference to and as shown in the accompanying drawings.

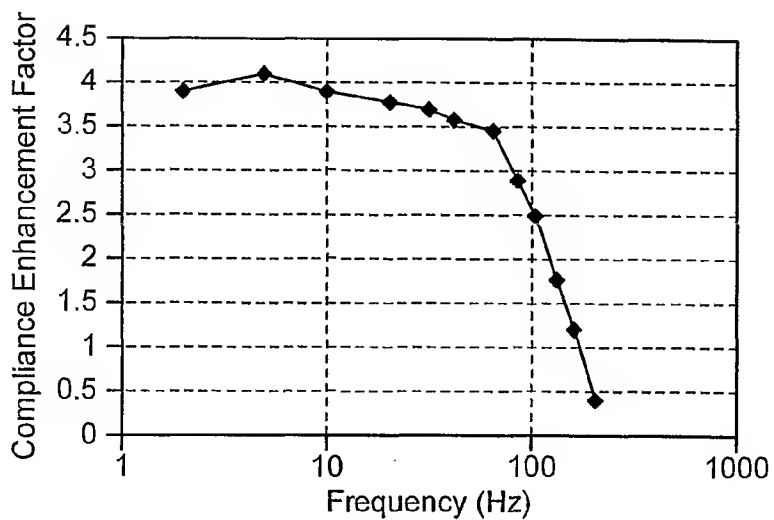18.   Any novel feature or combination of features disclosed
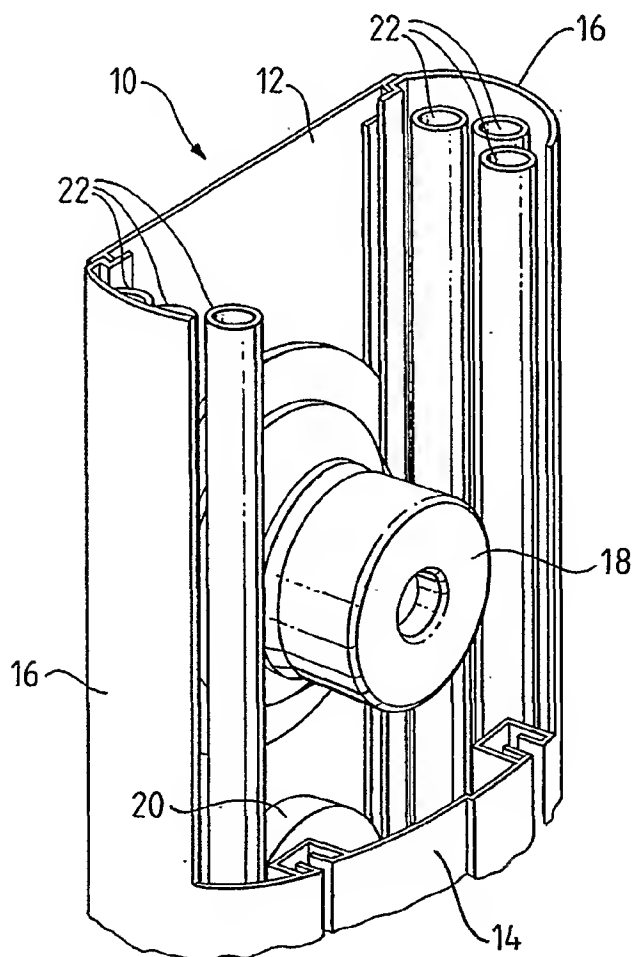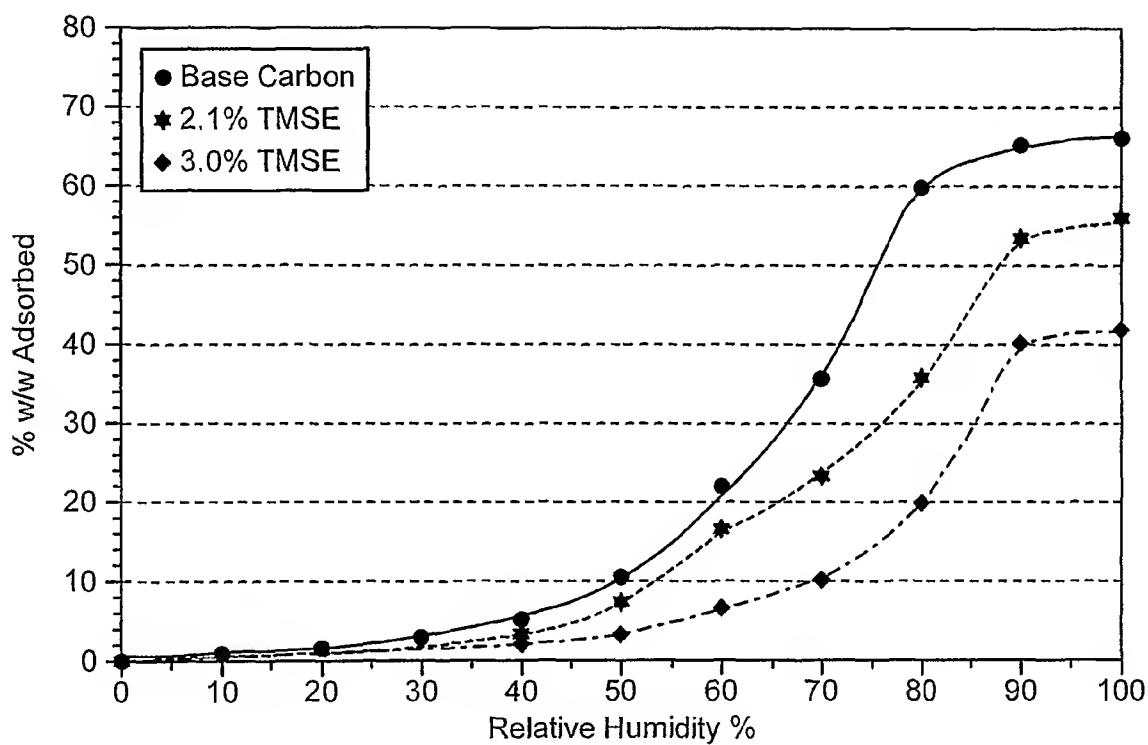30 herein.

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FIG. 1

FIG. 2

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FIG. 3